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Presumption of deterioration concrete strength by small size core and X-ray technique with contrast medium

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Abstract

This paper proposes a method of evaluating the strength of concrete below a degraded surface determined from an x-ray image taken of a 10 mm and 30 mm core cut from the insitu concrete. The image was enhanced by impregnation of the surface with a contrast medium. Several types of concrete having different water-cement ratio were used in the experiment. As a result, it is showed that the strength of concrete of even small cores can be estimate by the x-ray technique.

Résumé

Cette étude propose une méthode pour évaluer le degré de solidité d'une masse de béton sous une surface dégradée au moyen d'une radiographie aux rayons X réalisée sur des sections de carottes de 10 mm et 30 mm prélevées sur le béton in situ. L'image est améliorée en imprégnant la surface de l'échantillon avec un agent rehausseur de contraste. Plusieurs types de béton présentant différentes proportions d'eau et de ciment ont été utilisés dans l'expérience. Les résultats font apparaître que le degré de solidité du béton sur des échantillons même petits peut être estimé grâce à la technique des rayons X.

Keywords

X-ray technique with contrast medium, small size core, concrete strength, strength profiles

1 Introduction

Recently, estimation of concrete strength has been attempted in need of the durability diagnosis of concrete structures. However, accurate strength measurement is difficult by the generally practiced surface hardness method when the structure is deteriorated, as this method only measures the surface strength. For durability diagnosis, it is important to measure the deterioration area from the surface toward the inside of concrete. In this regard, accurate strength evaluation in the longitudinal direction is difficult by compression testing on drilled cores. And when the manager inspects the strength of insitu concrete structure by compression testing on drilled cores, it is more desirable for structure to take a small damage and not to cut the reinforcing bar. In Japan many reinforced concrete structures have the congested reinforcing bar for the earthquake countermeasure. Therefore it is demanded that the size of the core is smaller than the clearance of bar. With this as a background, the authors conducted a study to develop a method of estimating the concrete strength and determining the strength profile using an X-ray technique with a contrast medium [1, 2] and small size core.

2 Relationship between concrete strength and X-ray transmission dose

2.1 Outline of specimens

Air-entrained concretes having water-cement ratios (W/Cs) ranging from 30 to 80% were proportioned typically as given in Table 1 using high-early-strength portland cement, crushed stone, and river sand. The experiment began with fabricating 12 cylindrical specimens 100 mm in diameter for each strength level. Three of these were used for uniaxial compression testing, while nine were used for strength estimation by contrast X-ray. Among the nine specimens for strength estimation, three were used as they were but the others were used for drilling cores from them to obtain specimens 30 and 10 mm in diameter. Note that the 100 mm diameter specimens were used for comparing the estimation accuracy with small cores. Whereas 10 mm diameter specimens were used as they were, specimens 30 mm and 100 mm in diameter were used by cutting a slice 10 mm in thickness from the center, because the estimation of the strength profile at 10mm spacing from the surfaces of actual concrete structures was intended. Note that all specimens were left to stand in a thermo-hygrostatic room at 20°C and 60% R.H. for 24 h before strength estimation by contrast X-ray. Figure 1 shows how specimens were prepared and used for testing.

Table 1. *Mix proportion of concrete*

Max. size of aggregate (mm)	Slump (cm)	Air (%)	W/C (%)	Fine aggregate ratio (%)	Unit content (kg/m^3)				AE agent (C×%)
					Water	Cement	Fine aggregate	Coarse aggregate	
20	8±2	5.0±1.0	30	39	180	601	583	910	0.005
			40	41		451	663	952	
			50	43		361	726	960	
			60	45		300	781	953	
			70	47		258	831	937	
			80	49		225	879	913	

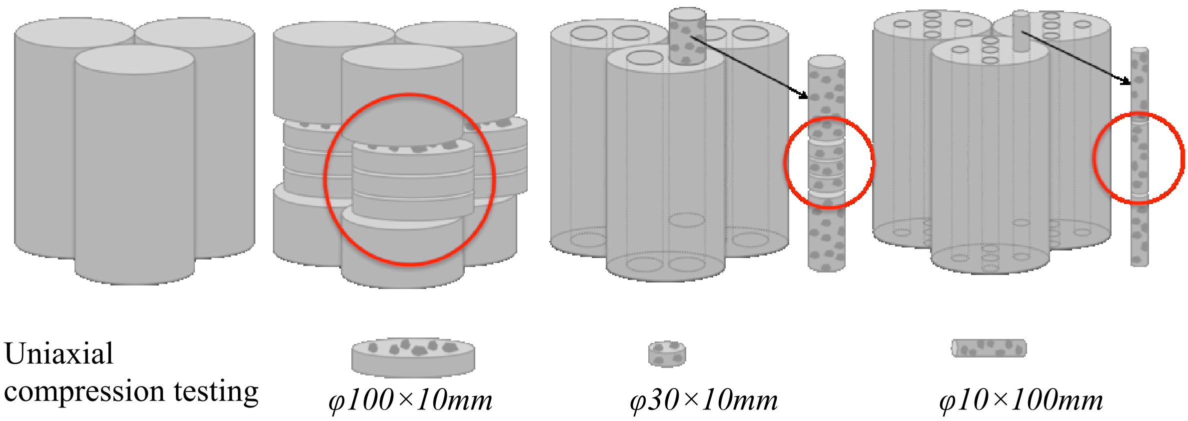

Figure 1. *Direction for specimens*

2.2 Contrast X-ray radiography

Contrast X-ray radiography is a method whereby concrete is impregnated with a liquid (contrast medium) having a high X-ray absorption coefficient to allow it to penetrate into voids and cracks and take X-ray images to visually detect such voids and cracks that are normally undetectable by visual observation.

Figure 2 shows examples of X-ray images (on X-ray film) before and after the impregnation with a contrast medium of concrete beams 100 by 100 by 400 mm in size with an initial strength of 48 N/mm^2 and air content of 3% and subjected to freezing and thawing testing specified in ASTM C 666 to reduce the relative dynamic modulus to 60%. Whereas the images before immersion in the contrast medium only shows aggregate and large voids, numerous voids and fine cracks can be detected from the images after immersion in the medium. This study proposes a method of estimating the strength of concrete by using this contrast radiography on small-diameter cores to detect and quantify voids and fine cracks that cannot be detected by visual observation.

Contrast X-ray images were taken under the conditions given in Table 2 before immersion in the contrast medium and 60 min after the immersion. The contrast medium was a 100 keV with a mass absorption coefficient of 0.18 cm^2/g developed at the authors' laboratories.

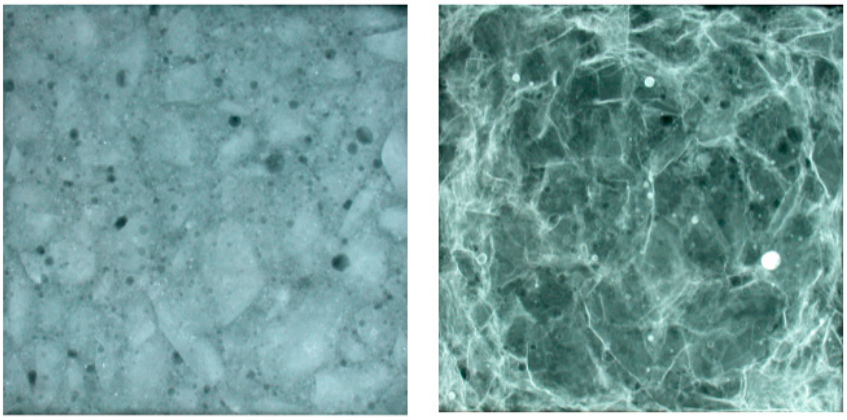

Figure 2. *X-ray images (left: Before the impregnation with a contrast medium, Right: after the impregnation with a contrast medium)*

Table 2. *Contrast X-ray images condition*

X-ray source (Toshiba I-311)	Tube voltage	50 (kV)
	Tube current	100 (mA)
	Focus dimensions	0.1×0.1 (mm)
	Focal distance	515 (mm)
Image intensifier	Toshiba 6-inch I/I	6 (inch)

Specimens were immersed in containers filled with the contrast medium to allow the medium to permeate into them without pressure. Specimens were removed from the containers, wiped with a rubber wiper to remove the excessive liquid from the surfaces, and subjected to X-ray radiography.

Figure 3 shows the state of taking X-ray images. Specimens were set under the conditions given in Table 3 before and after impregnation with the contrast medium. The X-ray images were loaded into a PC using an image intensifier. The grayscale of the obtained images is determined by the number of X-ray photons passing through specimens and reaching the detector (transmission dose). In other words, the X-ray transmission dose increases as air voids/cracks and materials with a low absorption coefficient increases. When an X-ray film is used as the detector, these areas look black. Conversely, the grayscale tends to be more transparent at areas of materials with a high absorption coefficient such as the contrast medium. In the case of concrete with many voids where the medium penetrates as the example shown in Fig. 1, the X-ray film before impregnation becomes darker and that after impregnation becomes whiter (when an image intensifier is used as the detector, the grayscale is reversed). The authors considered that air voids and fine cracks in concrete may be quantified by determining the difference between the transmission doses before and after impregnation of concrete with a contrast medium (hereafter referred to as "transmission dose difference").

For determining the transmission dose difference, it is necessary to determine the X-ray transmission dose. As the density of the transmission images is determined by the X-ray transmission dose on the image intensifier, it was decided that the density of transmission images be determined by measuring the density of the images. The density of transmission images loaded in a PC was expressed in terms of standard optical density.

$$D = \log (1/T) \tag{1}$$

where D = standard optical density, T = transmissivity

For specimens 30 mm and 100 mm in diameter, the central circles 25 mm and 80 mm in diameter, respectively, were selected as the areas of measurement in consideration of the effect of core drilling. For specimens 10 mm in diameter, the entire area was included in the area of measurement because of being small.

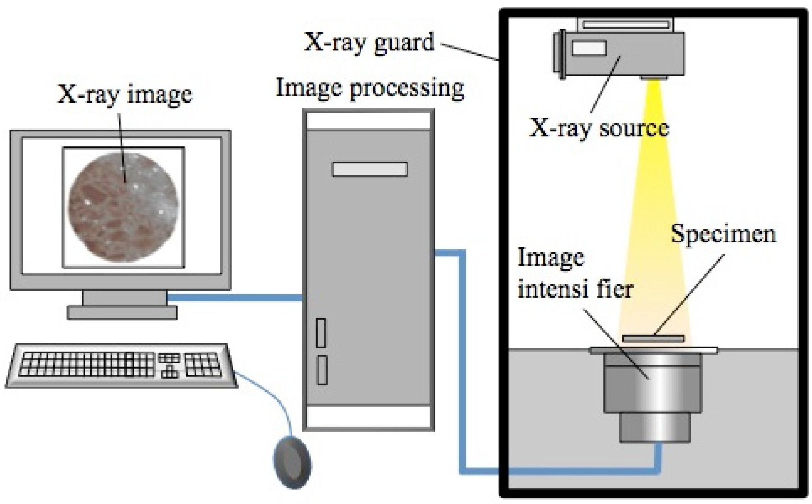

Figure 3. *State of taking X-ray images*

3 Relationship between concrete strength and transmission dose difference

Figure 4 shows the X-ray film images of 100 mm diameter specimens before and after impregnation with the contrast medium. As is evident from this figure, aggregate that scarcely transfers X-ray appears vaguely whitish and only large voids appear to be black before impregnation, but the contrast medium then penetrates into aggregate interfaces and small voids to be detected white. Note that X-ray film images taken after shooting with the image intensifier are shown in this paper, as X-ray images are clearer to see, though the image intensifier is used for estimating the strength of concrete in the present study.

Figure 5 shows the relationship between the transmission dose difference and the strength of concrete specimens 100 mm and 30 mm in diameter. The red and blue lines represent the transmission dose differences determined from specimens 100 mm and 30 mm in diameter, respectively. In regard to both types of specimens, the compressive strength tends to increase as the transmission dose difference decreases (the contrast medium hardly penetrates) and tends to decrease as the transmission dose difference increases (the medium easily penetrates). Also, the transmission dose difference of small diameter cores tends to show a greater scatter as the strength decreases. Presumably due to the effect of the defect in the concrete. Nevertheless, the strength strongly correlates with the transmission dose difference, suggesting the possibility of estimating the strength by determining the transmission dose difference. And an increased number of cores may reduce the effect of small core. Also, since this is a technique whereby 100 mm and 30 mm diameter cores are cut into 10 mm slices for X-ray contrast imaging to estimate the strength from the transmission dose difference, it is possible to determine the strength profile of 10 mm spacing from the surface inward when cores are drilled from the surfaces of actual structures.

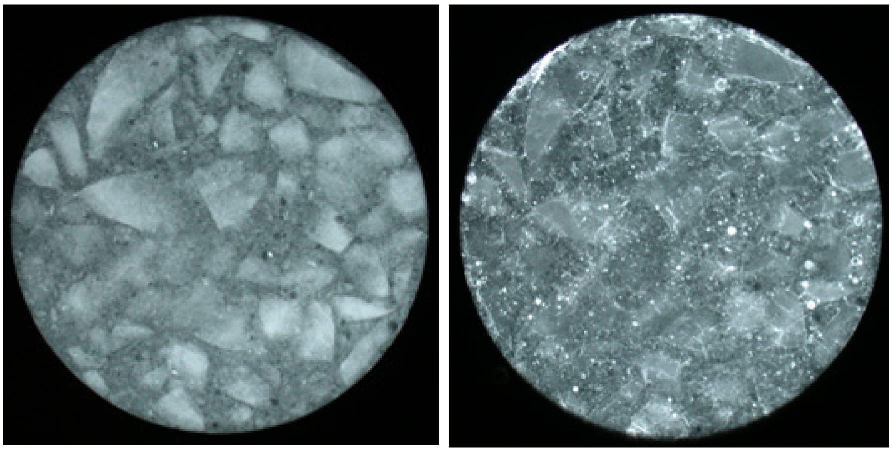

Figure 4. *X-ray images (left: Before the impregnation with a contrast medium, Right: after the impregnation with a contrast medium)*

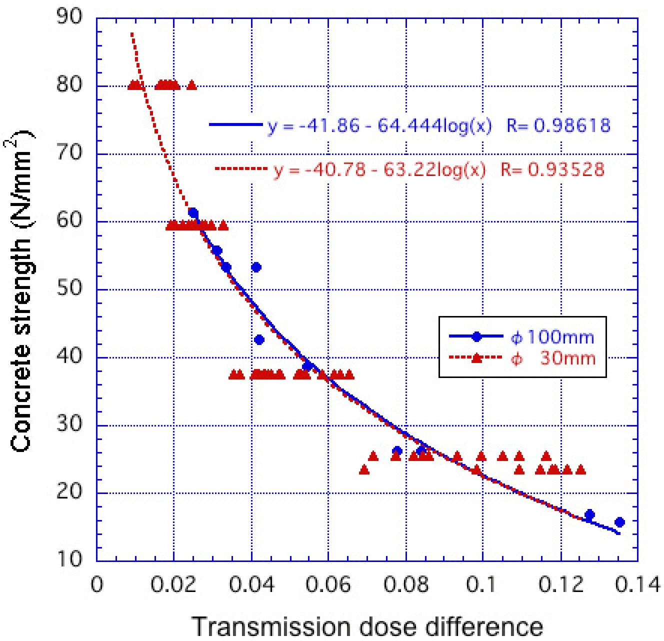

Figure 5. *Relationship between the transmission dose difference and the strength of concrete specimens (ϕ 100 mm and ϕ 30 mm)*

Figure 6 shows the relationship between the transmission dose difference and the strength of concrete specimens 10 mm in diameter. Similarly to 100 mm and 30 mm diameter specimens, the compressive concrete strength tends to increase as the transmission dose difference decreases. Also, the transmission dose difference of 10 mm diameter cores tends to show a greater scatter as the strength decreases similarly to 30 mm diameter cores. One reason for such a scatter can be the effect of drilling including fine cracks and breakage.

Another reason can be the effect of the defect in the concrete. An increased number of cores may reduce the effect of drilling, increasing the accuracy of strength estimation to a certain extent.

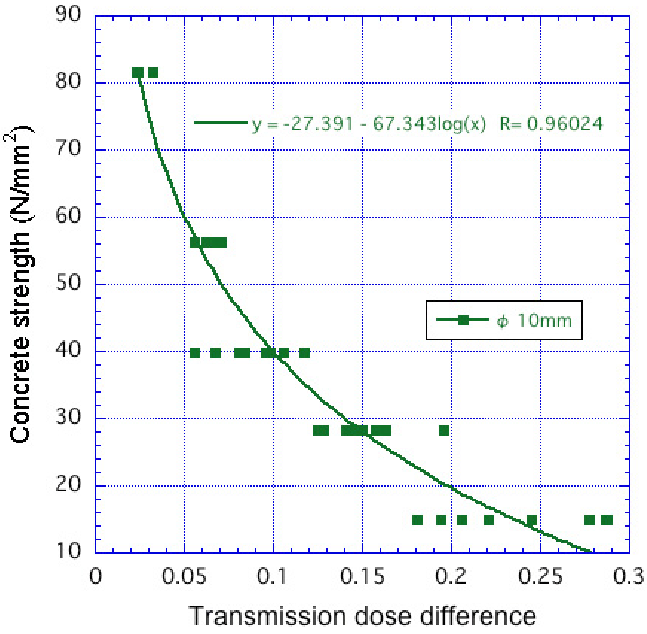

Figure 6. *Relationship between the transmission dose difference and the strength of concrete specimens (10 mm)*

4 Conclusions

Cylindrical specimens 10, 30, and 100 mm in diameter were used to determine the relationship between the transmission dose difference and the compressive strength of concrete. Within the range of this experiment, the following were found:

1. The strength of concrete can be estimated by determining the X-ray transmission dose difference using drilled cores 10 mm and 30 mm in diameter. The strength profile from the surface inward can also be estimated using drilled cores 30 mm and 100 mm in diameter

2. Though small diameter cores tends to show a larger scatter as the concrete strength decreases, the estimation of concrete strength using small diameter cores is considered feasible by increasing the number of cores.

References

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